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48104
P. 15

NASA Technical Memorandum 104742

Display Format, Highlight Validity, and Highlight Method:
Their Effects on Search Performance

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October 1991

National Aeronautics and
Space Administration

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Display Format, Highlight Validity, and Highlight Method:
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October 1991

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EXECUTIVE SUMMARY

Display format and highlight validity studies (Tullis, 1984; Fisher and Tan, 1989) have shown that these factors affect visual display search performance; however, these studies have been conducted on small, artificial displays of alphanumeric stimuli. A study manipulating these variables was conducted using realistic, complex Space Shuttle information displays. A 2 (display type: Orbit Maneuver Execute, Relative Navigation) x 2 (display format: current, reformatted [following human-computer interface design principles]) x 3 (highlighting validity: valid, invalid, no-highlight) within-subjects analysis of variance found significant main effects of these variables on search time. Search times were faster for items in reformatted displays compared to current displays. Responses to valid applications of highlight were significantly faster than responses to non-highlighted or invalidly-highlighted applications. The significant format by highlight validity interaction showed that there was little difference in response time to both current and reformatted displays when the highlight was validly applied; however, under the no-highlight and the invalid highlight conditions, search times were faster with reformatted displays.

A separate analysis studied the interaction between display format, highlight validity, and several highlight methods. The 2 (display format: current, reformatted) x 2 (highlighting validity: valid, invalid) x 4 (highlight method: brightness, color, flashing, reverse video) within-subjects analysis of variance did not reveal a main effect of highlight method.

In addition, observed display search times were compared to search times predicted by Tullis' Display Analysis Program (1986). Significant correlations between predicted and observed search times were found, although the relationship was highest with non-highlighted displays (r= .75) and was less predictive with valid (r= - .52) and invalid (r= .31) applications of highlight. Issues discussed include the benefits of highlighting and reformatting displays to enhance search, and the necessity to consider both highlight validity and format characteristics in tandem when predicting user search performance.

1.0 INTRODUCTION

Much research has examined factors which optimize operator search and selection of information from alphanumeric computer displays. Two particular issues have dominated this research in recent years: the effect of format characteristics on search performance has been the focus of work conducted by Tullis (1981, 1983, 1984), and the demonstration of search performance under different levels of highlighting validity has been addressed by Fisher, Coury, Tengs, and Duffy (1989), Fisher and Tan (1989), Tan and Fisher (1987), and Warner, Juola, and Koshino (in press). In Tullis' dissertation (1984), four format characteristics (overall display density, local density, number of groups, and average visual angle of groups) were significant predictors of the time needed to search for a single item of information in a display. Fisher and Tan (1989) found differences in highlight benefit under different levels of highlight validity: when highlight validity was less than 50%, performance with highlighted displays did not differ from performance with displays on which no highlight was present.

In a comparison of format and highlight as predictors of search performance, format can be viewed as the more basic of the two variables. The format of an information display is generally fixed: no changes are made to the overall layout of the information after the display has been implemented. It is at this point that highlight may be applied in order to increase target search and detection. In this sense, highlight may become a subsequent, "quick-fix" solution for poor display design.

However, some research has sought to identify format characteristics that influence search, thereby circumventing the need to apply highlight techniques. Characteristics included in this group are such display format variables as item alignment (Streveler & Wasserman, 1984), and display loading (defined as the percentage of active area on a screen) and grouping (Danchak, 1976).

Recently, much of the interest in format has been concentrated on the variables studied by Tullis (1984). Tullis initially proposed six display format characteristics as possible predictors of search time:

1) overall density- percentage of the total number of character spaces available on the display devoted to actual display characters;

2) local density- a weighted measure of how close characters were to each other within a 5-degree visual angle;

3) number of groups- a simple count of the number of groups on the display;

4) average visual angle of groups- a weighted average (based on the number of characters in a group) of the angles subtended by the groups of information on the display;

5) number of items- a simple count of the number of character items present on the display;

6) layout complexity- a measure of information alignment (vertical and horizontal complexity measures, based on information theory, are summed to provide a total measure of layout complexity).

Tullis' model was derived via a "regression by leaps and bounds" multiple regression, which provides the best-fitting regression model for each number of predictor variables. Tullis found that each of these search time regression models included at least one of the two grouping variables (i.e., number of groups or average visual angle of groups). The overall 6-predictor model accounted for 50.8% of the variance in his subjects' response times.

Tullis selected the 4-variable model (containing overall density, local density, number of groups, and size of groups), accounting for 48.8% of the variance, as the best model, since the variables in the 5-variable (adding the number of items variable) and 6-variable models did not add significantly to the prediction. This regression model forms the basis for Tullis' Display

Analysis Program (1986). This program evaluates the usability of alphanumeric computer displays, as defined by user search time, by providing a prediction of search time based on measures of these four predictors.

The present study, in part, provides the opportunity to determine how well the Tullis model predicts actual search time for more complex displays of information. Contrasting the response times from the present study and the predicted values from the model provides a measure of the extent to which the Tullis regression model predicts actual search performance. It must be noted that a difference between Tullis-predicted and observed response times could be relative (Tullis, 1986). Tullis has addressed this possibility: "the predicted search times . . . should be viewed as relative rather than absolute measures . . . " (p. 11). He has noted, "... although they [predicted response times] generally have correlated well with empirical data in the literature, the absolute values of the predictions have commonly been wrong . . . specifically, the predicted search times have often been too low" (pp. 11-12).

For example, a significant correlation would imply that poorly-designed displays had longer predicted search times, as found by both the Tullis predictions and the observed data. In this case, the Tullis assertion of predicted search times as relative would be supported.

Recent research has focused on highlighting as a potential method for enhancing visual display search performance. Highlighting is an obvious choice as an influence on the visual search of a display for two reasons: (a) color coding, as one example of a highlight application, has been demonstrated to be effective when searching for a target in an array (Christ, 1975), and (b) the widespread application of highlighting techniques in visual displays with little empirical research prompts an investigation of the implications of highlight use.

The possibility that highlight will be applied to a non-target display item is one such implication. In this event, the attention-attracting quality of highlight may actually be a hindrance to the search process. Research conducted by Fisher and Tan (1989) focused on the consideration that inappropriate application of color to a non-target item may increase search time to the target item. In their work, target search performance was found to be superior on those trials where the target was highlighted when compared to performance when a distractor was highlighted.

Both the validity and the format studies mentioned here have been conducted on displays containing small sets of stimuli. The present study investigated the impact of highlighting on display search performance with actual, complex alphanumeric information displays.

In the present study, highlight, format of the information display, and information display type were manipulated. It was predicted, based on the work of Fisher and Tan (1989), that compared to non-highlighted displays, valid highlighting would result in increased search performance and invalid highlighting would result in a decrease in performance. Performance was predicted to be better under display formats which followed good human factors practices than under the current display formats. An interaction between highlight validity and display format was predicted: It was hypothesized that performance under both display formats would be benefitted by highlight, but that there would be less benefit to highlighting reformatted displays. The two display types were not expected to result in different levels of performance, but were tested in order to provide a greater range of displays.

2.0 METHOD

2.1 Subjects

Twelve Lockheed Engineering and Sciences Company (LESC) employees voluntarily participated in the experiment. All subjects had normal or corrected-to-normal vision, and were unfamiliar with the experimental displays.

2.2 Stimulus Displays

Two current Space Shuttle displays, Orbit Maneuver Execute and Relative Navigation, were presented on an IBM PC/XT with a 13-inch color monitor. These alphanumeric displays were roughly similar in appearance, but they contained information particular to either the Orbit Maneuver Execute or the Relative Navigation task. Regardless of condition, the information occupied almost the entire display area of the monitor. The displays were identical to those used in Burns, Warren, and Rudisill (1985).

Each display type was presented under two kinds of format: current and reformatted. Format changes to improve the current navigation and orbit displays followed good human factors practices (e.g., grouping, alignment of numeric data values) and are enumerated in the Burns et al. paper. Examples of the current and reformatted versions of the navigation and orbit displays are shown in Figures 1 and 2.

Dan Bricklin's Demo II program was used to add highlighting to the displays and to present the stimuli during the study.

2.3 Experimental Design

The experiment followed a 2 x 2 x 3 within-subjects factorial design. The displays presented to each subject varied by combinations of display type (Orbit Maneuver Execute or Relative Navigation), display format (current or reformatted), and highlighting validity (valid, invalid, or no-highlight). Subjects were presented with two replications of each of the different display combinations. Each of the display type by format display combinations was presented twenty times. To avoid order effects, four random sequences of display presentations were used.

Highlight was present on 80% of the displays, equally divided into valid and invalid use of highlight. The highlighted item was either the target item (valid application of highlight) or a randomly-selected distractor display item (invalid application of highlight). The remaining displays (20%) had no highlight and served as a control condition for the use of highlight. When present, the highlight was one of the following techniques: brightness, color (blue), flashing, and reverse video. With the exception of the displays in the blue-highlighted condition, all displays were monochrome.

As in the Tullis (1984) experiment, the dependent measure in this experiment was time needed to supply an answer to a randomly-selected question concerning information contained in the display.

```
2011/033/            REL NAV             1 002/22:48:35
                                           000/00:01:39
 RNDZ NAV ENA 1*  SV UPDATE
 KU ANT   ENA 2*   POS  0.76              AVG G ON     5*
 MEAS     ENA 3    VEL  0.96             ■VX        +36.46
        NAV                              ■VY        -10.10
 SV SEL 4 FLTR      RR GPC               ■VZ        +31.74
 RNG     49.877  RNG      52.605         ■VTOT      479.40
 R    -    5.32  R    -     5.90          RESET COMPNT 6
 θt      358.48  EL       -  4.6                     TOT 7
 Y       - 0.24  AZ       +  1.1     |     SV TRANSFER
 Y       -  0.0  wP       +  1.0     |   FLTR MINUS PROP
 NODE 23:11:43   wR       -  0.3     |    POS         1.55
           FILTER                    |    VEL         1.02
 S TRK 12     RR 13    COAS 14*      |   FLTR TO PROP  8
 STAT              OFFSET X          |   PROP TO FLTR  9
                          Y          |   ORB TO TGT   10
 SLOW RATE      15*                  |   TGT TO ORB   11
 COVAR REINIT 16        MARK HIST          EDIT OVRD
         RESID  RATIO ACPT   REJ          AUT   INH   FOR
 RNG    + 1.99   0.0    0     0           17    18*   19
 R      - 0.38   0.0    0     0           20    21*   22
 V/EL/Y  -0.05   0.1   10     0           23    24*   25
```

```
2011/033/              REL NAV  1     MET 002/22:48:35
                                      CDT 000/00:01:39
*RNDZ NAV            S VCTR UPDATE
*KU ANT               POSTN        0.76   ■VX       + 36.46
 EXT SNSR MSRMT       VLCTY        0.96   ■VY       - 10.10
*PWRD FLT NAV                             ■VZ       + 31.74
 RESET ■V CMPNT      S VCTR FLTR          ■V TOTAL 479.40
 RESET ■V TOTAL      RNG          49.877
*SLOW RAT            RNG RAT -  5.32     RNDZ RDR GPC
 COVAR REINIT        θt         358.48     RNG        52.605
                     Y         + 0.24      RNG RAT - 5.90
 SENSORS             Y RAT   -  0.0        EL        - 4.6
  S TRK              NODE    23:11:43      AZ        + 1.1
  RNG RDR                                  wPITCH    + 1.0
* COAS               S TRK STATUS          wROLL     - 0.3

 S VCTR XFER         S TRK OFFSET
  FLTR TO PRPG        X
  PRPG TO FLTR        Y                     MRK HIST   EDIT
  ORB TO TGT                  RSDL   RTO   ACP   RJT   OVRD
  TGT TO ORB         RNG     + 1.99  0.0     0     0   INHT
  FLTR - PRPG        RNG RAT + 0.38  0.0     0     0   INHT
   POSTN 1.55        V/EL/Y  - 0.05  0.1    10     0   INHT
```

Figure 1. Examples of the current (top) and reformatted (bottom) Relative Navigation experimental displays.

2.4 Procedure

Subjects performed a computer-generated search and identification task. In each trial, a question concerning one item of Space Shuttle display information was presented (e.g. "What is the value for C1?", "What is the value for node?"). A set of twenty questions was used. The subsequent display contained the information needed to answer the question. Subjects were instructed to signal when they had found the information by pressing the Return key. Response time was defined as the time between information display onset and the press of the Return key. At this point, a response screen appeared and the subject typed the answer value for that question. Subjects received a short break after the first 40 displays. The experiment was self-paced; subjects generally completed the experiment within one hour.

```
2021/    /       ORBIT MNVR EXEC         1 009/16:52:33
OMS BOTH 1*                                000/00:37:31
        L 2          BURN ATT
        R 3           24 R 336
RCS SEL  4            25 P 134         ■VTOT       56.7
5 TV ROLL 180         26 Y  15         TGO         3:02
TRIM LOAD            MNVR 27
 6 P   - 1.2                           VGO X +   43.20
 7 LY + 0.7                                Y -    7.60
 8 RY - 1.2          REI                   Z +   15.40
9 WT 209265          TTA  15:25
10 TIG                     GMBL              HA      HP
  009/17:30:04.8           L      R    TGT 147    +132
TGT PEG 4            P  +1.5  +2.3     CUR 147    +129
 14 C1     ____      Y  +0.6  +1.1
 15 C2   + _.____
 16 HT    ___.___    PRI 28*  29*    35 ABORT TGT
 17 θT    ___.___    SEC 30   31
 18 PRPLT + _____    OFF 32   33       FWD RCS
TGT PEG 7                                ARM  36
 19 ■VX  + __56.7    GMBL CK  34         DUMP 37
 20 ■VY   + __0.0                        OFF  38*
 21 ■VZ   + __0.0    EXT ■V            SURF DRIVE
                                         ON   39
```

```
2021/   /       ORBIT MNVR EXEC  1  MET 003/00:09:28
                                    IGT 003/00:10:28.0
 SELECT ENGINE   BRN ATTITUDE       CDT 000/00:01:00
* BOTH OMS        ROLL     335      BRN LENGTH  1:33
  LF OMS          PITCH    179
  RT OMS          YAW      347      ■V TOTAL      46.5
  RCS
                 SLP/INTRCPT GDC    VELOCITY TO GO
 ENGINE DRIVE     C1       __2530    X       +   45.70
  PRMRY LF        C2      +0.7500    Y       -    0.21
  PRMRY RT        HT     100.500     Z       +   47.33
* SCNDY LF        θT     _78.350
* SCNDY RT        PRPNT  + _____               CUR  TGT
                                    APOGEE     130  130
 FWD RCS BRNOFF  EXT ■V GDC         PERIGEE   +118 +122
  ARM             ■VX   + ____._
  DUMP            ■VY   + ____._     GIMBAL SETTINGS
                  ■VZ   + ____._               CUR  TGT
 LOAD                                PTCH LF +0.3 +0.4
 START CDT       TRJ VCTR RL 180     PTCH RT +0.5 +0.4
 START MNVR      WEIGHT   204025     YAW  LF -1.4 -1.7
 GIMBAL CHECK                        YAW  RT +1.8 +1.7
 SURFACE DRIVE   RNG TLS
```

Figure 2. Examples of the current (top) and reformatted (bottom) Orbit Maneuver Execute experimental displays.

3.0 RESULTS

3.1 Analysis of the Factorial Design

A 2 x 2 x 3 (Display Type x Display Format x Highlight Validity) analysis of variance (ANOVA) revealed that significant display type differences were present, $F(1, 132) = 12.09$, $p < .001$. Subjects took longer to respond to the navigation displays than to the orbit maneuver displays (mean response time = 17.51 and 13.29 seconds, respectively). The main effect of display format was significant, $F(1, 132) = 7.22$, $p < .01$. Response time to the reformatted displays was significantly shorter (mean = 13.77 seconds) than response time to the current displays (mean = 17.03 seconds). There was a significant difference in the time needed to respond under the three highlight applications, $F(2, 132) = 22.42$, $p < .0001$. As expected, a Student-Newman-Keuls comparison of means showed that mean response time to valid applications of highlight (9.66 seconds) was significantly shorter than mean response time to displays in which no highlighting was present (18.00 seconds) and to invalid applications of highlight (18.54 seconds) at the $p < .05$ level. The difference in response times to no-highlighting displays and displays with invalid application of highlight was not significant.

Display type did not enter into any of the higher-order significant interactions. Among these higher-order interactions, only the format by highlight validity interaction was significant, $F(2, 132) = 3.62$, $p < .05$. For the current displays, a Scheffe test showed a significant difference between valid highlight (mean = 9.04 seconds) and the other highlight validity conditions ($p < .05$). There was no significant difference between no-highlight (mean = 21.20 seconds) and invalid highlight (mean = 20.86 seconds) for current displays ($p < .05$). For the reformatted displays, there was a significant difference between the valid (mean = 10.28 seconds) and invalid (mean = 16.22 seconds) conditions ($p < .05$). The no-highlight condition (mean = 14.81 seconds) did not significantly differ from the other conditions ($p < .05$). The interaction is illustrated in Figure 3.

3.2 Factorial Analysis of the Highlighting Methods

In this section, the difference in response times to several highlight methods was investigated. In order to accomplish this analysis, the no-highlight trials were dropped from the analysis. The data was collapsed across display type for two reasons: (a) the effect of highlight under the different display types was not of interest, and (b) display type did not interact with either the display format or the highlight validity variables in the above factorial. The analysis followed a 2 (display format: current, reformatted) x 2 (highlight validity: valid, invalid) x 4 (highlight method: brightness, color, flashing, reverse video) within-subject design.

The 2 x 2 x 4 ANOVA revealed that the main effect of highlight validity was significant, $F(1, 176) = 63.53$, $p < .0001$, as in the above analysis. Response time to valid highlight (mean = 9.48 seconds) was significantly shorter than response time to invalid highlight (mean = 18.46 seconds). Response time to reformatted displays (mean = 13.09 seconds) was shorter than response time to current displays (mean = 14.85 seconds), but the main effect of display format was not significant, $F(1, 176) = 2.46$, $p < .12$. The main effect of highlight method was not significant, $F(3, 176) = 1.65$, $p < .18$. Response times to the highlight methods were as follows: color (mean = 12.23 seconds), flashing (mean = 13.46 seconds), brightness (mean = 14.60 seconds), and reverse video (mean = 15.59 seconds).

Among the higher-order interactions, only the display format by highlight validity interaction was significant, $F\ (1, 176) = 6.93$, $p < .01$, similar to the previous analysis.

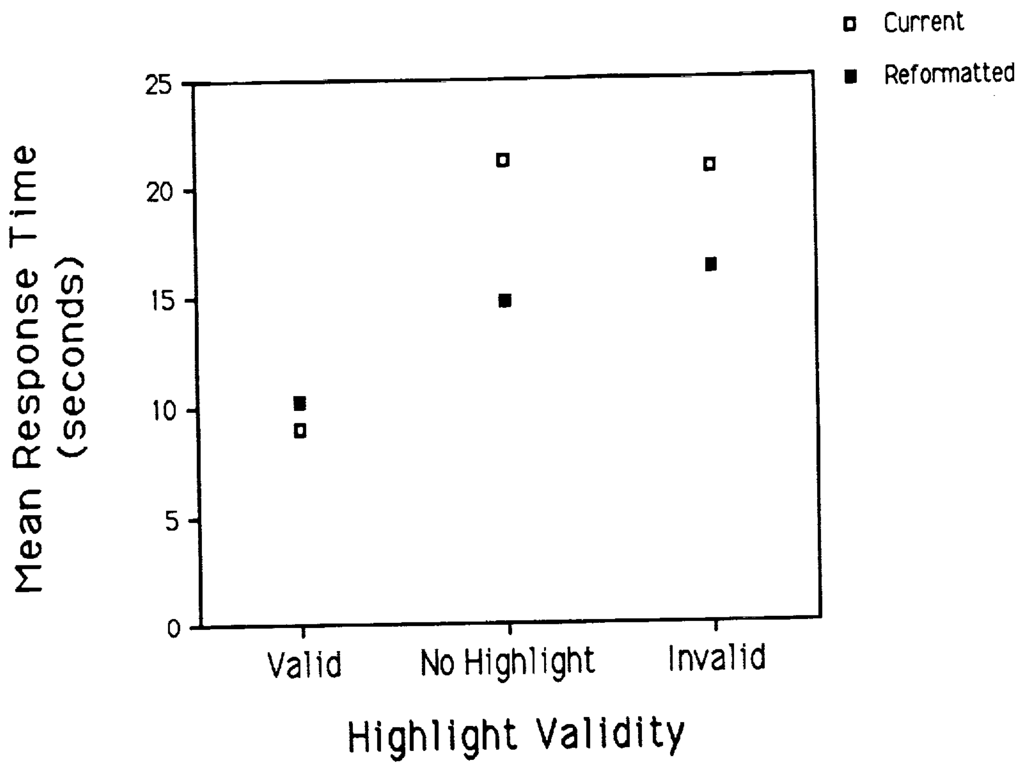

Figure 3. Mean response time as a function of highlight validity and display format.

3.3 Observed and Predicted Search Time Performance

Of interest in this section was the correlation between the observed display search times and the Tullis-predicted search times. Using Tullis' Display Analysis Program (1986), the experimental displays were evaluated on overall density, local density, number of groups, average visual angle of groups, number of items, and format complexity. The program also provided measures of predicted search time for each experimental display.

The correlation between predicted and observed search time varied, depending on the validity or presence of highlight. The correlation between predicted and observed search times for non-highlighted displays was high and significant, $r = .75$, $p < .0001$. The correlation was lower for displays with valid ($r = -.52$) and invalid ($r = .31$) applications of highlight, although both sets of correlations were significant at the $p < .05$ level.

Although the association between observed and predicted search times was strong, the predicted search time values and the observed values differed in magnitude. The overall Tullis-predicted mean search time was 3.4 seconds. This predicted time was similar under all of the highlight validity conditions, since the Tullis model calculated predicted search times without using highlight as a factor. The overall observed search time was much longer (15.4 seconds). As stated in Section 3.1, the mean observed search times for the valid, no-highlight, and invalid highlight conditions were 9.66, 18.00, and 18.54 seconds, respectively.

4.0 DISCUSSION

The present study strengthens the generalization of previous display format and highlight validity findings taken from studies using more artificial, less complex information displays.

The important findings centered around the highlight validity and the display format manipulations. In this study, significantly shorter search times resulted from both an application of highlight on the appropriate item of information and a reformatting of the current displays.

Performance was best when highlight was validly applied to a target item, regardless of the display format. Despite less than optimal display format in some conditions, items were found quickly simply because the subject's attention was drawn to the lone highlighted item on the display. This highlight benefit was not dependent on the method of highlight.

Format became an issue when the highlight was either not present or was invalidly applied. In these situations, the user's task involved search through the display. In both of these conditions, the search was made faster by display redesign.

The impact of display format on search performance in this study offered two interesting findings. A reformatting of the current displays had a significant influence on the speed with which subjects could locate items on a display, with subjects searching the reformatted displays more efficiently than the current displays. A search performance benefit of highlight was only found under the current displays: the addition of highlight did not aid user search more than a re-grouping of display items. The reformatting was based upon general formatting principles such as alignment and grouping.

In addition, this study demonstrated that Tullis' Display Analysis Program predicts actual search performance with complex, as well as simple, displays. This correlation was highest with the non-highlighted displays, and decreased with the application of display highlight. This finding suggests that, in the absence of other factors affecting search (e.g., highlighting), these format characteristics are strong predictors of performance. However, the lower association under highlighted conditions is evidence that format characteristics should be considered together with other search factors when attempting to optimize the prediction of user search performance.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
October 1991

3. REPORT TYPE AND DATES COVERED
Technical memorandum

4. TITLE AND SUBTITLE
Display Format, Highlight Validity, and Highlight Method:
Their Effects on Search Performance

5. FUNDING NUMBERS

6. AUTHOR(S)
Kimberly A. Donner, Tim D. McKay, Kevin M. O'Brien, Marianne Rudisill

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lyndon B. Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBER
S-654

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D. C 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA TM-104742

11. SUPPLEMENTARY NOTES
Donner, McKay, and O'Brien--Lockheed Engineering and SciencesCo.
Rudisill--Johnson Space Center, Crew Station Branch (SP3)

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified--Unlimited
Publicly Available
Subject Category 54

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)
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14. SUBJECT TERMS
Man-Computer Interfaces, Human Factors Engineering, Display Devices

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited